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SUPERSONIC TRANSPORT VIS-A-VIS ENERGY SAVINGS

G. Cormery

Translation of "Le transport supersonique face aux economies
d'energie," L'aeronautique et l'astronautique,
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16. Abstract The place in the economy of a supersonic transport plane is justified. This place can be realized with a Concorde derivative, and perhaps later with a second-generation TSS.					
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SUPERSONIC TRANSPORTATION VIS-A-VIS
ENERGY SAVINGS
(Le transport supersonique face aux
économies d'énergie)

by

G. Cormery

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General Comments

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Supersonic transportation vis-a-vis energy savings.

The first instinct is to see a certain contradiction in this association of words.

And yet, the hypocrisy is that, at a convention dedicated to the theme "Energy Savings by Technical Innovation," the problem of supersonic transportation has not been addressed.

What I fear is to be unable to deal thoroughly with this subject, since the examination of the problem in all of its aspects is of such complexity to make one dizzy.

Furthermore, this question of supersonic transportation vis-a-vis energy savings is only a small part of a much more general problem, which could be named "Optimal Use of Energy for the Good of Humanity."

This proposition may seem somewhat pedantic and yet this

*Numbers in the margin indicate pagination in the foreign text.

is the kind of motivation which must guide our thinking. This means that, no matter how the subject is treated, it is necessary to admit that the results run the risk of being biased in the human sense and, more specifically, when the selected criterion is just an economic criterion; by this I mean one which is too simplistic and concerns only a small part of the whole field.

It is, however, necessary to return to more basic proposals. This must be done with prudence, though, since we often tend to confine a problem within an isolated system where thinking seems so simple that one risks forgetting the essential.

This is the reason my only intent for this article is to set the scene without dodging the questions which must be posed, even if at present they remain insoluble.

The preparation of this work, to which unfortunately I have not been able to dedicate as much time as would have been necessary, has led me to the following observations:

- It is extremely difficult if not impossible to find a world synthesis of real and temporary energy consumptions.
- Accessible documents concern mainly the United States.
- Each industrial corporation must certainly tackle the problem of energy savings, but motivations, in other words, the criteria selected, vary and do not proceed from a general strategy.
- The depletion of natural resources of oil seems inevitable but its final date cannot be specified since it depends on actions taken on a world scale.

The problem is certainly alarming, but I think that timely solutions do exist on the condition that we conquer egotism in its

two forms, human and economic.

It is evident that I will neglect various aspects of the problem but I prefer that others discover them. If today I can make some contribution, I will be satisfied.

Air Transportation and Energy

I am posing the problem from the perspective "Air Transportation and Energy" rather than "Supersonic Transportation and Energy" on purpose. This is, in fact, the smallest generalization which can be made to respond to the concerns expressed in the introduction.

Presently, fuels extracted from natural oil are the only sources of energy used by aerodynes.

But for how much longer?

This is an important question because the research and development strategy for aeronautical materials depends not only on the response given, but also on the timely selection of the form or forms of substitution energy.

It is evident that air transportation will be able to adapt to other energy sources such as methane or liquid hydrogen, but when this will occur, it will be a question of global change in subsonic and supersonic transportation. Table 1 gives, as an example, the distribution of large energy consumers in the year 1970 for CEE (Common Market) and the U.S.

From these approximate figures we can make two general observations:

-- Air transportation receives a very small portion of the total energy distributed.

-- Air transportation in the European Community is underdeveloped

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as compared to the U.S.

	CEE	USA
Industry	43%	44%
Small Consumers	37%	26%
Transportation	20%	30%
Total	100%	100%
<u>Air transportation</u>		
Total transportation	7%	13%
<u>Air transportation</u>		
Total Energy	1.4%	3.9%

Table 1. Energy Use, 1970

We shall now examine a more restricted transportation field, using the consumption of oil fuels in the U.S. between 1970 and 1985 as seen by NASA (Table 2).

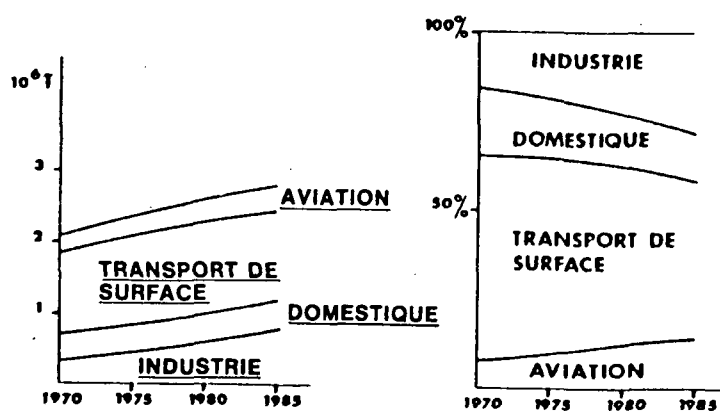


Table 2. Oil consumption in the U.S. (Source: NASA).

Key:

1. Aviation	3. Domestic
2. Land transportation	4. Industry

I am using the example of the U.S. as the one country which best represents our medium term future as we, in Western Europe, are moving, though with some delay, toward this economic model.

In addition, the U.S. is the country where energy waste is most notorious.

The main observations which can be made based on these graphs are:

- The prediction of a consumption increase slows down in the period 80-85 influenced by energy saving policies.
- The increase in industrial consumption does not seem to change.
- Air transportation grows substantially in comparison to land transportation.

These observations lead me to two main conclusions:

- The first is that no one, upon examining future energy problems, can indict the existence of air transportation.
- The second is that the anticipated outlay in the area of oil fuel /5 economy does not seem well apportioned.

From the perspective of the number of "km x passenger" transported by Kg of fuel, air transportation is in the worst position among all means of transportation, the steamboat excluded.

In addition, as far as medium length travel is concerned, especially in Europe, it is the most expensive means of transportation.

Air transportation continues its progress, nonetheless. It is, therefore, from the economic point of view, in the larger sense, that the network composed of airplane and engine builders, the consumers of this means of transportation and the various sections of the general economy as well as the airlines has a dynamic potential

for progress.

It is then certain that air transportation cannot be sacrificed on the altar of energy moralism and that minimum consumption will probably never be the only optimization criterion.

Speed, taken somewhat into account in the formulations of DOC, is an economic parameter, the effects of which can be quantified with difficulty, though undeniable.

Supersonic Transportation within Air Transportation

Starting from the hypothesis that the existence of air transportation is not being indicted, supersonic transportation will develop to the point where it will be able to find its place within the world fleet.

Supersonic transportation will develop, because it already exists with Concorde.

The problems presented by the Concorde plane have nothing to do with energy problems.

The noted noise problems are false problems, since they still exist with subsonic planes which do not meet FAR 36 noise standards,

With an annual rate of use between 2800 and 3000 hours, the Concorde plane is proving profitable in its adaptation stages.

Consequently, although the economic crisis of air transportation has certainly been an important factor, the causes for the Concorde difficulties must be looked for outside noise problems, the energy crisis or simple profitability.

Naturally, this plane can be perfected and the decision on whether or not to carry out these improvements is quite important for its consequences.

I am digressing so because all the technical literature concerning future supersonic transportation speaks of the second generation. This implies the existence of a first generation represented by the Concorde and Tupolev 144 planes on the condition that these programs are pursued and developed as they should be.

Supersonic transportation is then a present reality and it must be judged within the current economic and ecological context, without reservations and prejudices.

In addition, it is clear that the world must recognize the existence of a natural oil shortage and put in motion safeguard programs which allocate replacement energy for air transportation.

If a second generation of air transportation does exist, it will probably be realized operationally in the nineties. We can say, without any great risk or error, that the fuel used will still be kerosene.

The most important studies currently carried out on the subject in the U.S. confirm this hypothesis.

Furthermore, it seems that classic criteria will still be employed to judge the viability of the program with both builders and users.

This will be true, of course, if there isn't a quota system for oil. If there is, all classic optimization criteria will have to be abandoned.

The result would surely be an extraordinary upheaval, the consequences of which cannot be measured.

However, as I have mentioned, there is an understanding of energy problems which directs aeronautical research in the direction of energy savings at substantially constant speed.

This technological effort, no doubt undertaken with the return to the rate of economic growth of air transportation in relation to the increase in the cost of oil as primary motivation, will result in a modification of the values of profitability criteria.

Supersonic transportation will have to accomplish improvements in cost and consumption to demonstrate its value in a long-range air network.

To pinpoint the progress which must be made, it is helpful to show progress made in the subsonic field, as seen by NASA.

Table 3 shows progress hoped for in propulsion materil, namely a 15 to 20% reduction of the specific consumption of engines in flight.

Certain authors, by combining somewhat boldly possible improvements, predict an increase in specific range of action on the order of 40%.

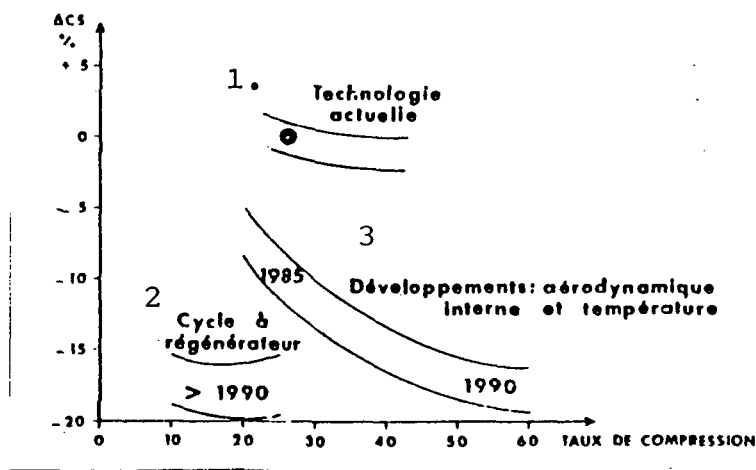


Table 3. Improvements hoped for in subsonic propulsion (turbofans).

Key: 1. Present technology 3. Developments: internal aerodynamics and temperature
 2. Regenerator cycle
 4. Compression rate

Short/Medium Term Technological Innovation

Technological progress advances, especially in the case of air transportation, through periods of concept development, followed by improvements and so on.

The supersonic Concorde plane represents a concept development in air transportation.

Will it be perfected during the improvement period which usually follows?

I cannot answer this question. It raises, in fact, national and international issues which are not directly tied to technology.

Conversely, technology tells us that an improved version of Concorde is feasible at short/medium term.

This improved version shows progress in the two main areas which are the focus of present concern:

- energy savings,
- noise reduction.

Detailed knowledge of the airframe and engine, supported by precise inflight measurements, makes it possible to determine anticipated improvements with great precision.

Studies carried out between 1973 and 1975 have made it possible to define and evaluate airframe improvements. The main ones are listed below:

- Project modification of the shape of the wing extremity, resulting in a small surface increase.
- Installation of mobile leading edges on the whole wing span.
- Improvement in aerodynamic efficiency by reduction of the wave trail.

These modifications, concern particularly the tapering of the radome and of the leading edges on the wing extremity and lee-board, as well as a reduction and adjustment of the lower flap of air in-flow.

- A mass reduction in structure and system both by design modifications and by use of new materials such as Kevlar and Carbone.
- An effort to reduce costs by detailed analysis of all parts of the plane.

It must be noted that this study has required the designing of a rotating control, for the regulation of the leading edges, the small size of which has made it possible to place it sideways along the wing-span.

As far as propulsion is concerned, during the same 73-75 period, various improvement means have been considered.

The most promising direction, particularly as far as noise reduction is concerned, consists of:

- an increase of air mass flow of about 25% during take-off and in flight and about 35% during approach.
- Acoustic processing of ejection and air in-flow systems.

These engine modifications make it possible to:

- conserve the high pressure section and operate at the same turbine in-flow temperature values,
- eliminate the afterburning system,
- achieve power savings throughout the whole range and specifically /7 in supersonic flight,
- achieve specific consumption savings throughout the whole range and specifically in transonic speed.
- function at high air flow and low power with, as immediate conse-

quence, an important reduction in ejection speed and associated jet noise.

		Aerodynamic efficiency C_x/C_x		
	C_x	Plane A	Plane B	Savings
Zero slope speed	0.77	3.94	4.24	7.6%
TAKE-OFF Second segment	0.61	4.97	5.58	12.3%
Anti-noise procedure	0.48	6.00	7.38	23.0%
APPROACH	0.60	4.35	4.75	9.2%
WAIT-- 250 knots, 10000 feet	0.28	9.27	13.10	41.3%
SUBSONIC CRUISING $M = 0.93$	0.20	11.47	12.92	12.6%
SUPERSONIC Present Engine CRUISING	0.125	7.14	-	7.7%
15A - 5° C Improved Engine	0.152	-	7.69	

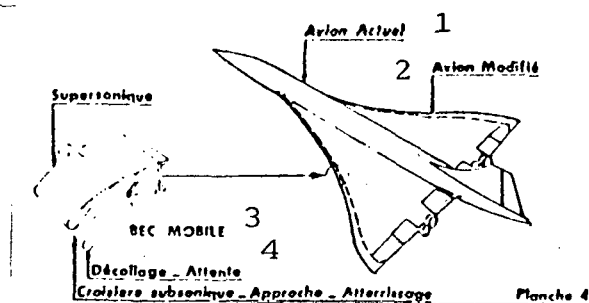


Table 4. Concorde development. Aerodynamic improvements.

Key: 1. Present plane 4. Take-off - Wait - Subsonic
 2. Improved plane Cruising - Approach - Landing
 3. Mobile edge

Table 4 gives an outline of the aerodynamic efficiency gains made by means of aerodynamic modifications.

We can see that savings made in the subsonic and supersonic fields are quite substantial.

Table 5 concerns again estimated improvements on the Paris-New York service.

These noise level values take into account possibilities presented by automatic power reduction systems after take-off and decelerated approach.

We must note that the operational use of a moderate linear wait will bring about consumption savings of 2 to 3% and will make it possible to achieve a global savings on the order of 15%.

Here is a summary of probable technical improvements which are accessible to a supersonic transportation plane deriving directly from Concorde.

1 CONFIGURATION	2 BRUIT EPN dB				3 CONSOMMATION
	LATERAL	SURVOL	APPROCHE	TOTAL	
7 AVION ACTUEL MD = 181,4 t	4 112,2	5 119,5	6 116,7	348,4	78950 kg
8 AVION MODIFIE MD = 177,6 t	109,1	107,1	109,1	325,3	69360 kg
9 GAINS	3,2	12,5	7,7	23,4	9620 kg (12%)

Table 5

Key: 1. Configuration 4. Lateral 7. Present plane
 2. Noise 5. Flight 8. Modified plane
 3. Consumption 6. Approach 9. Savings.

I must state that the above values, particularly as far as propulsion is concerned, derive from my own evaluations.

My objective is to show that we can take a big step in improving Concorde and that these improvements will have to be able to eliminate prejudices and criticisms which have plagued the plane in its present form.

Development costs inherent in this operation are high yet lower than those we might expect for a second generation supersonic plane which reaches the objectives described in technical literature.

An in-depth market study will have to support the viability of such a project and it is evident that a plane of this kind should be the object of wide range cooperation.

Long-Term Technological Innovation

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Limit Conditions and Technologies

Technical advances far more considerable than those described so far can be conceived.

When will they be made? I think that it is premature to set dates and state relative solutions.

We have undertaken studies for a second generation plane and I sincerely believe that ten years of efficient work will be needed before a general design, based on technological solutions, will make it possible to reach a desired performance level.

As everyone knows, the U.S. has launched a basic exploratory program on the subject with implementation funds about which we Europeans can only dream.

However, the work has started and I shall describe its outline.

The first possibility we are going to explore is a direct derivation of the improved version of Concorde with the following features:

- Cruising speed $M = 2.0$ to 2.2
- Delta wings without optimized and lift-increased tail unit
- Primary structure in light alloy.

Conversely, the first studies employ a double-flux reactor with low bypass ratio.

These studies are carried out in cooperation with S.N.E.C.M.A. and we agree that other solutions relating to propulsion will have to be found.

Our intention is to design progressively better solutions as to appreciate more deeply technical problems and their uncertainties.

Table 6 shows the objectives and the definition and restriction criteria which have been set at the beginning.

A basic hypothesis concerns environmental restrictions in the nineties, especially in relation to noise which practically defines the plane.

The choice of the 16 O.A.C.I. standard as the noise level objective is a minimum and it will be necessary to examine the possibility of attaining lower noise levels while evaluating losses in consumed fuel and cost which are associated with this restriction.

OBJECTIVES, DEFINITION AND RESTRICTION CRITERIA

- Operation during the last decade of the century,
- Choice of range of action and capacity covering most stages with significant anticipated trade,
- Commercial load x range of action criterion
Take-off mass improved by 60 to 80% in relation to Concorde,
- Sufficient profitability for builders and users,
- Selection of technological advances realizable in specified time,
- Infrastructure restrictions (runway length, pavement resistance)
- Operational restrictions (Reserves, procedures, grounding of supersonic aircraft in certain areas),
- Anticipated environment restrictions (pollution, noise). For noise: 16 O.A.C.I. standard as objective.

Table 6. Second generations TTS

As a first step, we have planned a service the features of which are described in Table 7. It represents the average flight of the supersonic system in question.

We can make two observation:

--The service includes substantial subsonic flight as several of its stages consist of flight above land.

--Anticipated reserves fit in a classic present day plan. We cannot be sure that in the nineties there will be a change in traffic regulations in terminal areas.

Table 8 features the technologies to be perfected from the aerodynamic point of view.

One can see that we have deliberately neglected the use of a limit control. This does not mean that we are not interested in it, but we do not believe that these techniques will be applicable in the 1990's.

DESCRIPTION OF FLIGHT		ATMOSPHERIC CONDITIONS
TAKE-OFF	Runway length: 3500 m	Sea level ISA - 100 Without wind
ACTIVE SERVICE	4700 NM of which 630 are subsonic at the start of flight	15A - 5° Front wind, 13 Km
WAIT AT END OF FLIGHT	30 minutes at 10000 ft. 250 kl	
DIVERSION	240 NM	15A, no wind
WAIT AT END OF DIVERSION	10 minutes at 10000 ft. 250 kl	
FINAL MANEUVER	10 minutes at 1000 ft. 200 kl	

Table 7. Second generation TTS

In addition the instruments for aerodynamic calculations at our disposal are sufficiently powerful to carry out a very precise analysis of the different aerodynamic configurations to be explored.

Table 9 shows the different wing shapes presently studied in the subsonic and supersonic fields.

TECHNOLOGIES TO BE IMPLEMENTED: AERODYNAMICS

- Complete optimization of volume and lift drag in supersonic range (air law, twist, arch)
- Increase in subsonic aerodynamic efficiency by:
 - use of leading edge flaps,
 - use of trailing edge flaps and C.A.G. concept or guide-vanes.
- Reduction of pod drag (Low inclination air in-flow, interaction optimization)
- Reduction in size of fin (lateral C.A.G. concept)
- Integrated servocontrol.

Table 8. Second Generation TTS

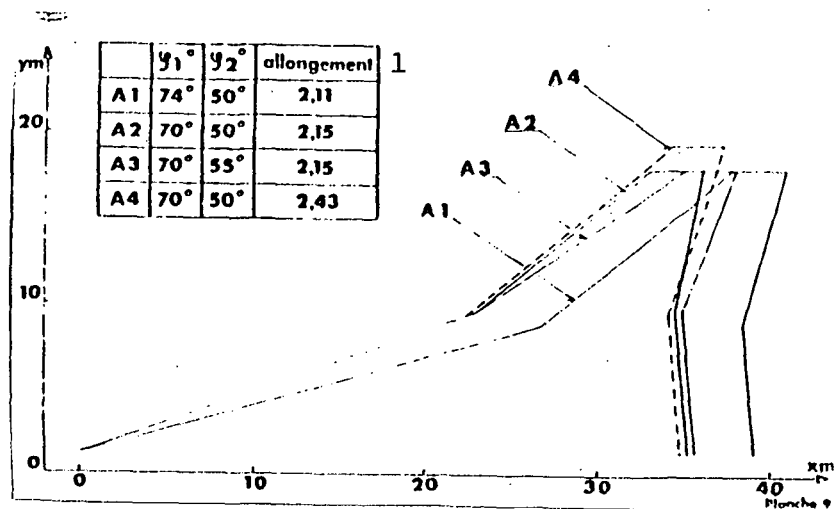


Table 9

Key: 1. Lengthening

Table 10 shows a model based on supersonic aerodynamic calculations.

Table 11 lists the technologies to be implemented from the point of view of propulsion.

As far as the air in-flow and the pods are concerned, it seems that the general design of the plane accomodates easily isolated rotating pods which make a considerable power gain possible as compared to the bidimensional Concorde type pods.

This is why we have emphasized the structural and aerodynamic concept of a rotating air in-flow.

Table 12 shows the operational principles of such an air in-flow for the various flight conditions.

Table 13 shows the structural concept we have arrived at.

Aerodynamic tests have been carried out at Soufflerie de Vernon and air in-flow efficiency of 0.96 at $M = 2$ has been achieved, equivalent to that obtained with bidimensional Concorde air in-flows.

As far as the engine itself is concerned, it is clear that this is the most important component and the success or failure of the projects rests upon it.

The examination of a plane with double-flux engine at moderate /11 bypass ratio constitutes only a first step and other solutions such as variable cycle and/or inverse ejection speed engines with or without silent retractable units, etc., will have to be studied.

Also in those areas we possess numerical analysis methods which are quite powerful and help carry out good structural predetermination.

As far as the knowledge of carbon structures is concerned, we have enough experience to be able to meet without problems the requirement of designing primary structures.

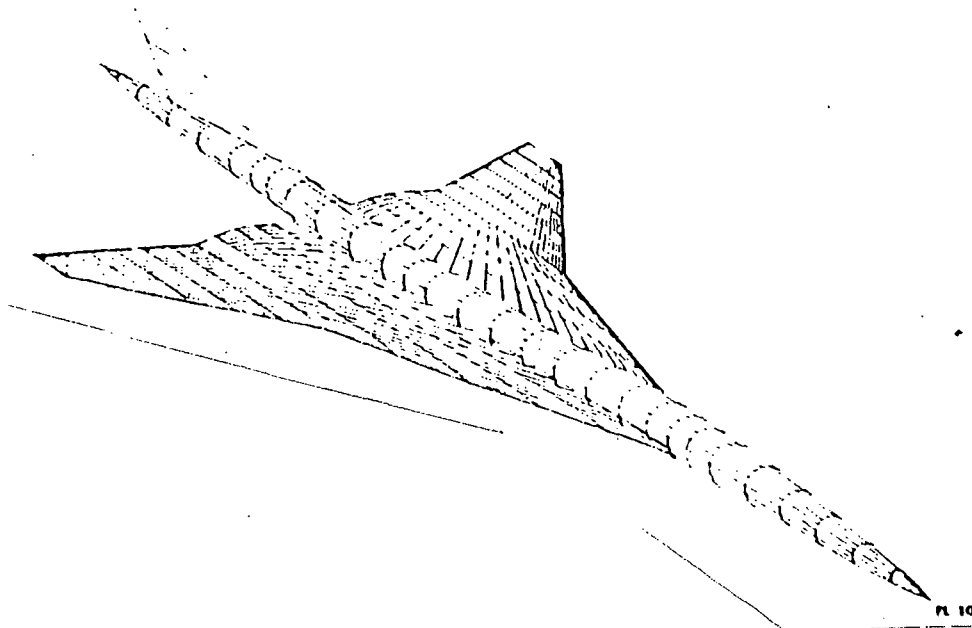


Table 10. Aerodynamic model

TECHNOLOGIES TO BE IMPLEMENTED: PROPULSION	
ENGINE:	Double flux, moderate bypass ratio; Increased temperature in front of turbine; Improved blade aerodynamics; reduced number of stages; Cycle adaptation (Variable stators, discharges, primary nozzle with changeable throat)
AIR IN-FLOW	Concorde type, with shortened diffuser nozzle and reduced hull inclination, or... Rotating, shortened, maintaining autoregulation in-flow principles of the Concorde type, or... Internal supersonic compression artificially stabilized, hull with low drag;
NOZZLE	Optimized during supersonic cruising; Reduced losses without adaptation;
ACOUSTICS	Jet noise reduction (low ejection speed, silent undercarriage); Acoustic processing; Precautions in design of turning parts.

Table 11. Second generation TSS

Conversely, for titanium structures, we must make an effort not so much in terms of knowledge but in terms of industrialization.

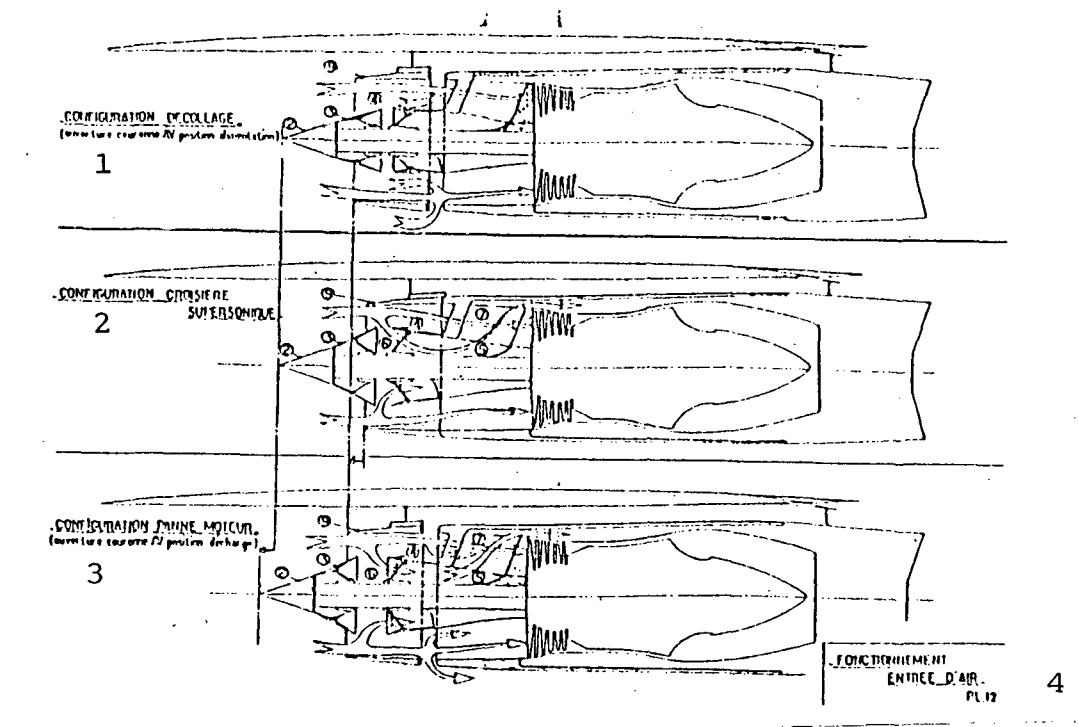


Table 12

Key: 1. Take-off configuration
 2. Supersonic cruising configuration
 3. Engine failure configuration
 4. Air in-flow operation

Table 15 lists the technologies to be perfected for the systems.

Electric flight controls and a certain level of active control are already on the present Concorde plane.

Furthermore, we have already developed an entirely electric flight control system, without final mechanical recourse but with numerical calculator and flight regulations adapted to flight in negative static range. This system is ready for installment on an experimental Concorde plane.

These are various directions we are exploring.

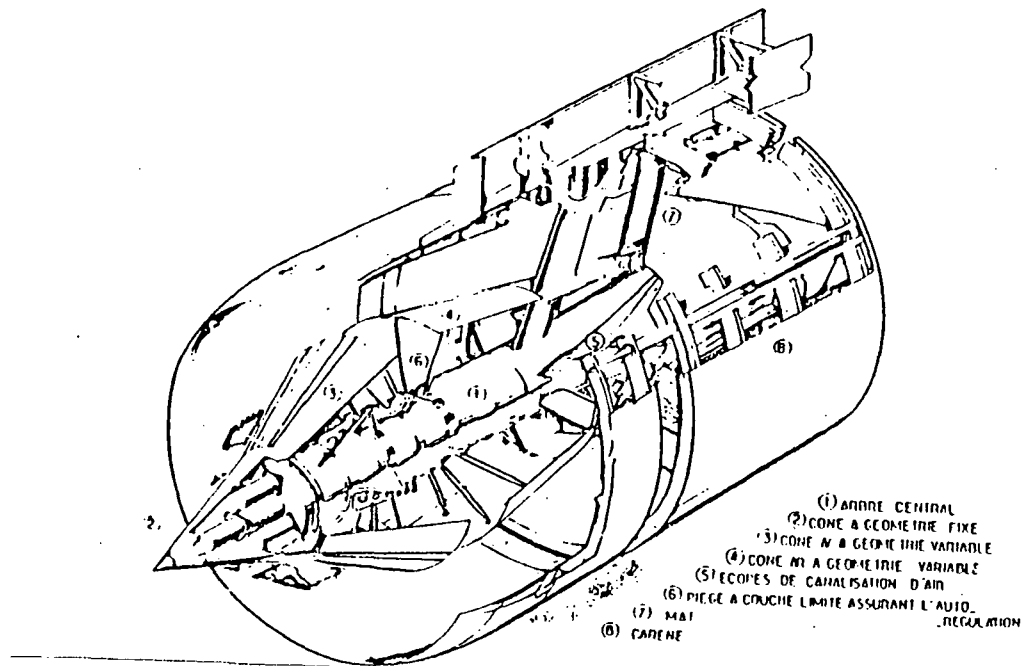


Table 13. Air in-flow

Key: 1. Central shaft	5. Air channeling scoops
2. Fixed geometry cone	6. Limit trap for autoregulation
3. Variable geometry cone N	7. Strut
4. Variable geometry cone AR	8. Body

TECHNOLOGIES TO BE IMPLEMENTED: STRUCTURES

- Establishment of restrictions imposed by static and dynamic aeroelasticity on the selection of design form;
- Precise determination of aero-thermo-elastic equilibrium forms;
- Use of compound materials:
 - Kevlar type for commercial installations
 - Carbon or boron fibres for secondary and some primary structures
- Greater use of titanium
- New structural concepts adapted to anticipated forms and sizes

Table 14. Second generation TSS

There is another direction which does not depend on the builders of aeronautical materials but is of great importance since it can lead to substantial fuel savings.

It is an organization of aerial traffic, especially in terminal areas and ground infrastructures, which can reduce waits and probable diversions involving unreasonable transportation of reserve fuel on the plane. /12

For supersonic planes, the "classic" reserves can reach 20% of the fuel transported. This quantity is greater, in mass, than the transported commercial load.

It is necessary, therefore, to avoid at all costs the transportation of kerosene by the planes.

One of the most promising solutions which is applicable to all planes but is especially well suited to supersonic planes consists of a linear wait, by means of advanced in-flight information, which shortens the final wait by reducing cruising speed.

This solution, employed rationally and safely, will make it possible to reduce reserves in half, bringing about savings of 10% on consumed fuel.

Quantitative Values

An elaborate computer calculation program has been implemented to obtain solutions which conform to all imposed restrictions.

Table 16 gives, for a certain bypass ratio, the sphere of existence of planes conforming to in flight restrictions as well as take-off runway, runway resistance and fuel volume restrictions.

Point M represents the optimal plane within the considered range and all points in this field can be scaled according to noise

level in lateral flight and approach.

TECHNOLOGIES TO BE IMPLEMENTED: SYSTEMS

- Electric flight control and general active control enabling:
 - High-lifting by control of trailing edges and reduction of ground clearances;
 - Moderate dimensioning of fin;
 - Lighter controls;
 - Simplification of fuel circulation system.
- Multiple information circulation by cables or optical fibers for better physical organization of components.
- System integration (for example, thrust control).
- Numerization increase;
- Automatization of thrust control at take-off and decelerated approach to reduce noise

Table 15. Second Generation TSS

Table 17 shows the evolution of the take-off mass of optimal planes as a function of the bypass ratio.

We can see a considerable decrease in profitability when the bypass ratio increases.

In addition, within each range designed for each bypass ratio, we can trace the evolution of the minimal take-off mass as a function /13 of noise level during take-off.

These functions are traced in Table 18 and we can see that:

- the optimal plane is the one with direct flux engine, but it can never reach the desired noise level;
- for a given bypass ratio, noise in flight decreases as the take-off mass, in other words the size of the plane, increases;

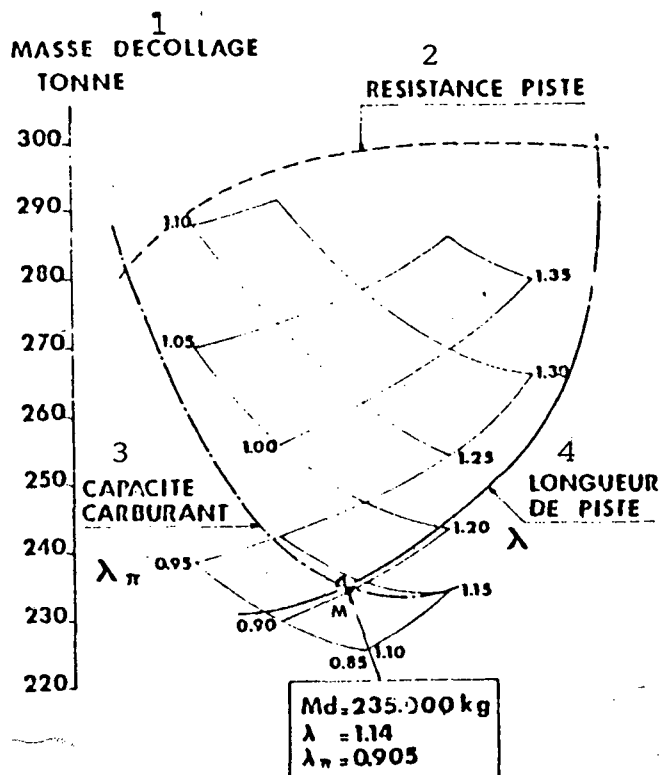
-- a low bypass ratio makes it possible to meet the OACI 16 standard requirement without any considerable efficiency loss.

Key:

1. Take-off mass in tons
2. Runway resistance
3. Fuel capacity
4. Runway length

Key (Table 17):

1. Take-off mass in tons
2. Bypass ratio



Key (Table 18):

1. Noise in flight
2. Take-off mass

$\sigma = 0.46$ C.C.V 38% S.C.T $\lambda_t = 0.9$ $N = 200$ $n = 6$

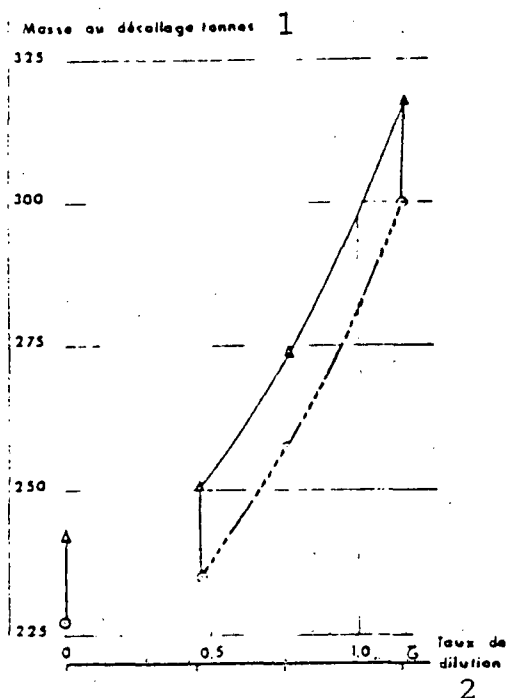


Table 17.

Table 16.

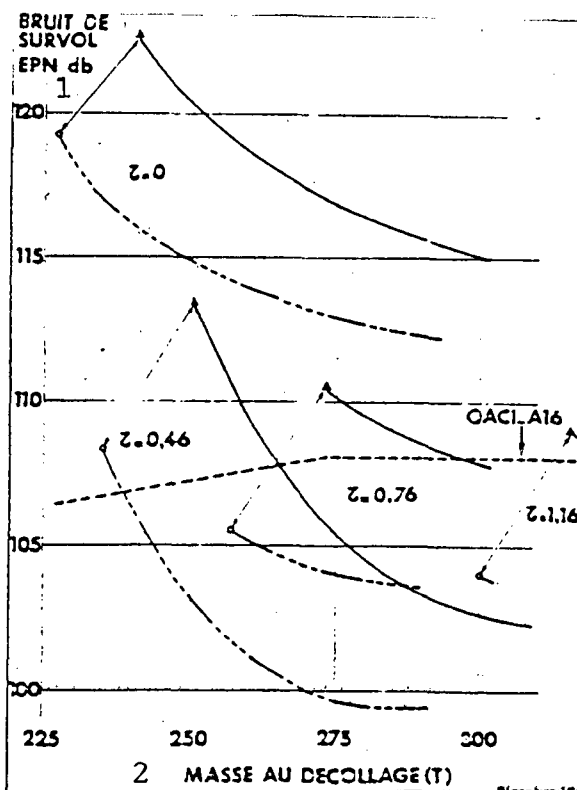


Table 18.

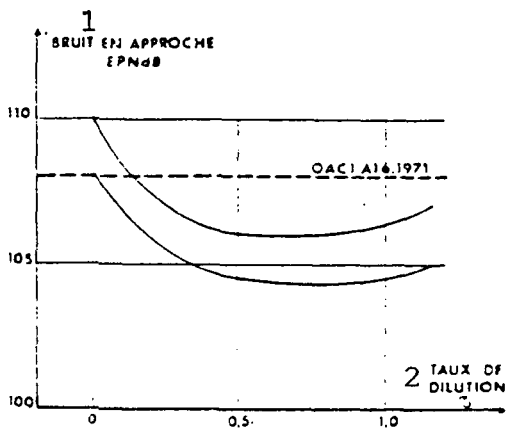


Table 19.

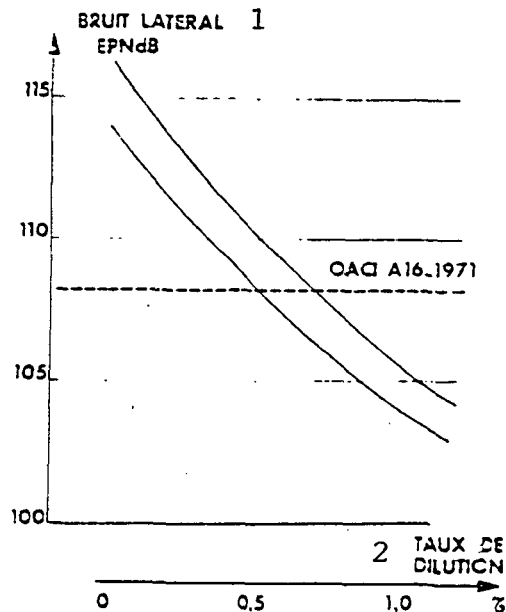


Table 20

Table 19 shows that noise during approach depends only on the bypass ratio and it becomes stationary and satisfactory with a low bypass ratio.

Table 20 is less pleasant. It shows that lateral noise also depends solely on bypass ratio but this parameter must reach at least a value of 0.6 to 0.7 for a satisfactory situation. This restraint increases the take-off mass by 30 tons as compared to the optimal plane at zero bypass ratio.

As the focus of this conference is supersonic transportation vis-a-vis energy savings, I have chosen to speak mainly about noise.

In fact this is the most difficult constraint for this kind of plane and it limits energy savings which could be accomplished.

Conclusion

Despite the brevity of the outline of problems I have discussed,

I believe the following conclusions can be made:

-- It is certain that there will be a shortage of oil fuels and that a strong motivation to economize is necessary. Waste must be eliminated and a political and economic policy for just apportionment can only be implemented with international consensus.

-- It will be necessary to begin organizing the right means for the processing of substitution fuels such as synthetic hydrocarbons, liquid methane and liquid hydrogen, etc.

-- Despite all this, air transportation is not doubted by anyone and, for at least two future plane generations, kerosene will remain the used fuel.

-- Furthermore, the optimization criterion will not be only minimal consumption research but rather, as it is today, a compromise between consumption and speed.

In this context, a supersonic transportation plane has a justifiable place in the economy, if it reaches certain objectives. This plane can be realized in the medium term with a Concorde derivation, in the long term with a second generation TSS.

In conclusion, I would like to add that studies and research in the direction of energy savings are important and necessary. This is something that concerns everyone and because of this the research cannot be supported only by builders; it must be the object of cooperative government support.